Experimental and numerical characterization of sandwich debonding behaviour

E. Petersen, J. Bopp, C. Hühne

In cooperation with Airbus – Defense and Space under the German research project “Forschungsverbund Oberstufe”

A. Dröse, V. Gröne

AIRBUS DEFENCE & SPACE

DLR

Content

- Motivation
  - Application
  - Sandwich part
- Test campaign
- Cohesive Modelling
  - Parametric studies
  - Results and comparison
- Conclusion and Outlook

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Motivation

Ariane 5

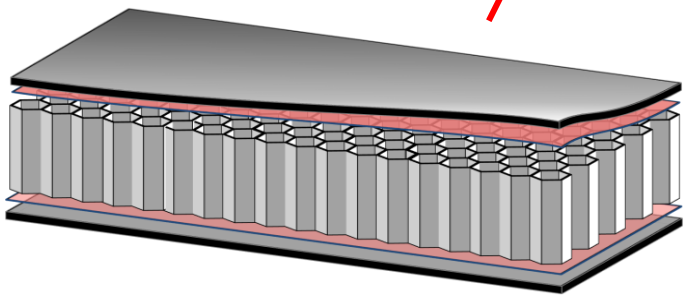
Sandwich parts e.g. Vehicle Equipment Bay

Safe life concept

The largest undetectable defect is not allowed to lead to failure

Debonding can occur through manufacturing or in operation

How to prove residual load carrying capacity?

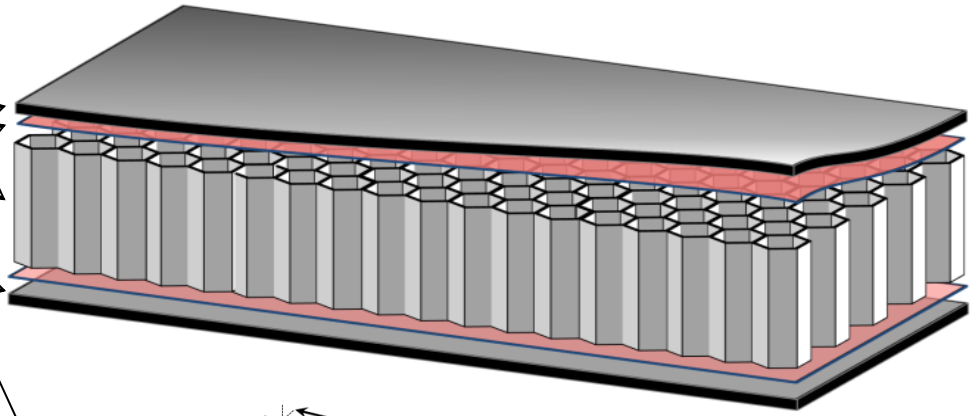


Arianespace – *Ariane 5 User's Manual Issue 5* – 2008

Sandwich Structure

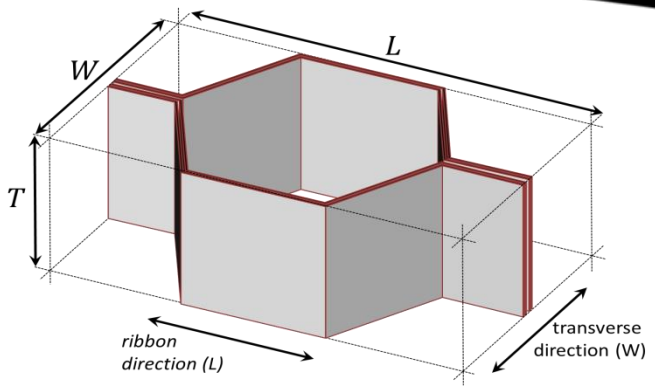
Bonding of:

- Aluminium honeycomb core
- CFRP face sheets
- Film adhesive



Principle:

- Core height leads to high parallel axis theorem
- High stiffness/weight quotient



Risk:

Disconnection (debonding) leads to loss of good mechanical properties

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Test matrix

Bondline coupon tests:

- Strength
- Fracture mech.

Compression tests:

- Artificial failure spots
- Structural behavior

Level	Aim	Test setup	specimen No.		Short
Coupon	strength Rz	ASTM-C-297	5 (3)		FWT
Coupon	fracture Glc	Experimental leaned on ASTM-5528	5 (3)		SCB
Part level	structural behavior	ASTM-C-364	Defect		
			Size Ø	No.	
			0	3 (5)	EWC-WOD
			18 mm	3 (5)	EWC-DB18
			24 mm	3 (5)	EWC-DB24
			36 mm	3 (5)	EWC-DB36

Test matrix

Bondline coupon tests:

- Strength
- Fracture mech.

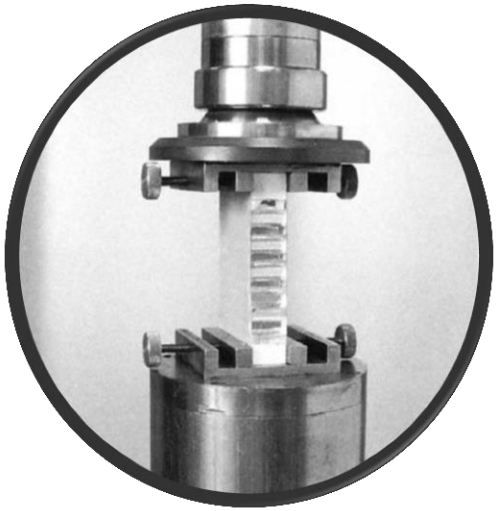
Compression tests:

- Artificial failure spots
- Structural behavior

Development of new test and manufacturing method

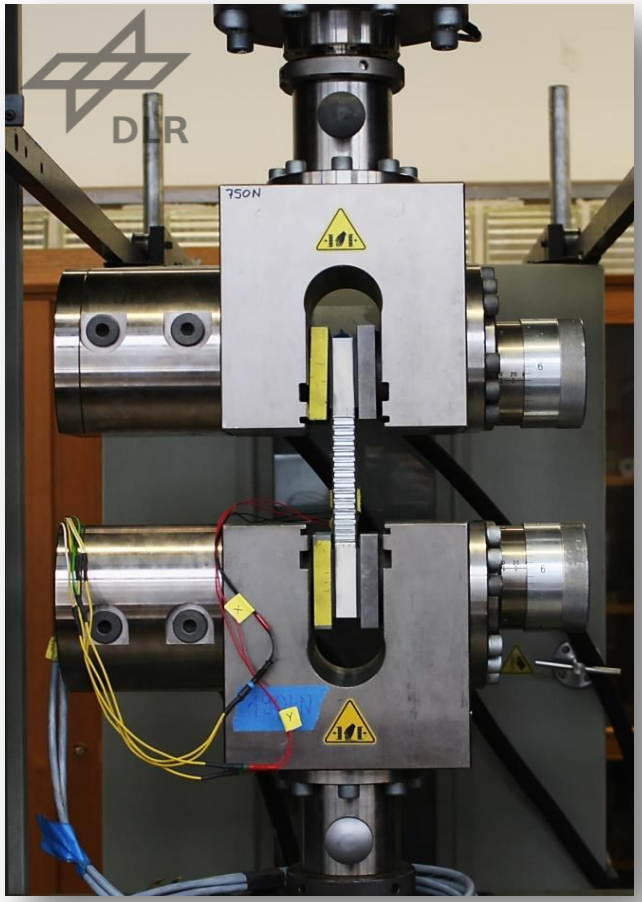
Level	Aim	Test setup	specimen No.		Short
Coupon	strength Rz	ASTM-C-297	5 (3)		FWT
Coupon	fracture Glc	Experimental leaned on ASTM-5528	5 (3)		SCB
Part level	structural behavior	Unfeasible under project requirements	Defect		
			Size Ø	No.	
			0	3 (5)	EWC-WOD
			18 mm	3 (5)	EWC-DB18
			24 mm	3 (5)	EWC-DB24
			36 mm	3 (5)	EWC-DB36

Test and manufacturing method



ASTM-C-364

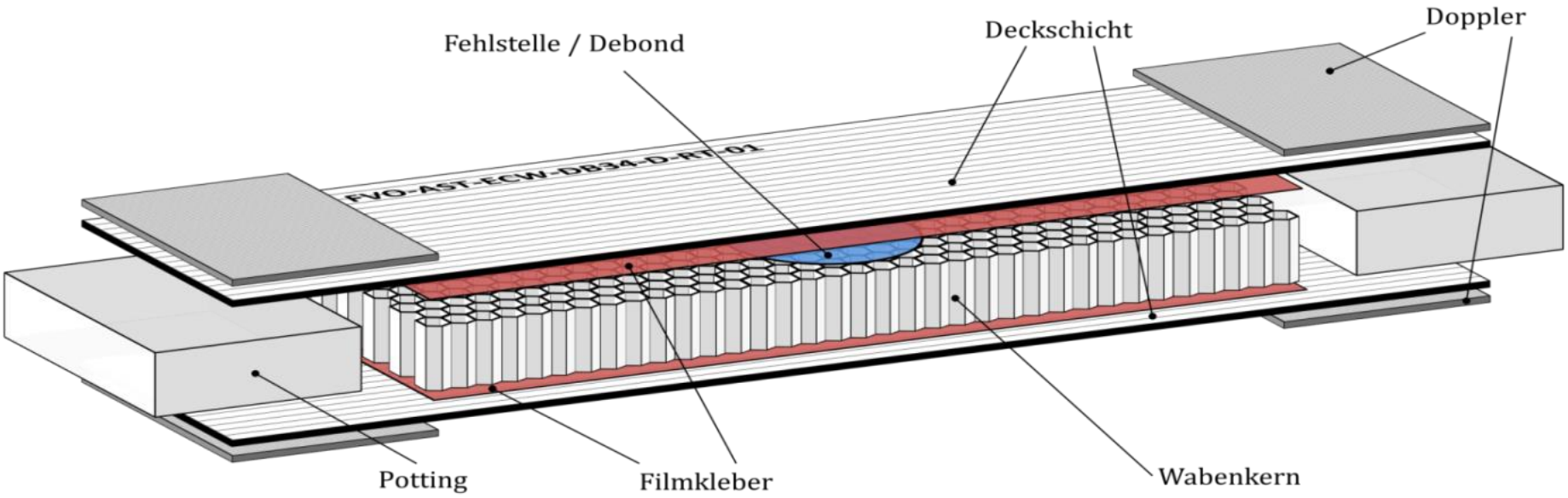
requirements



New test and manufacturing method

- Allows manufacturing in one step
- Allows potting
- Load introduction through clamping with hydraulic pressure
- Accessibility for optical measurements

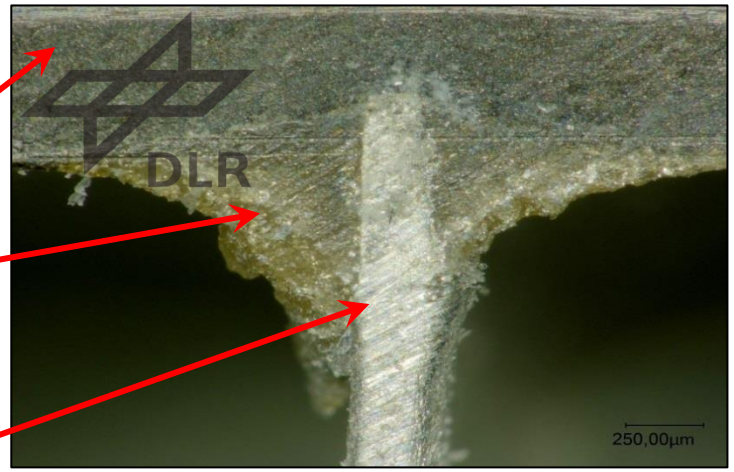
Test and manufacturing method



Application for patent Nr: DE 10 2013 108 645.4 *„Verfahren zur Herstellung eines Prüfkörpers sowie Prüfkörper zur Bestimmung der Druckfestigkeit von Sandwichbauteilen“*

Characterization of bondline

Microscopy of bondline



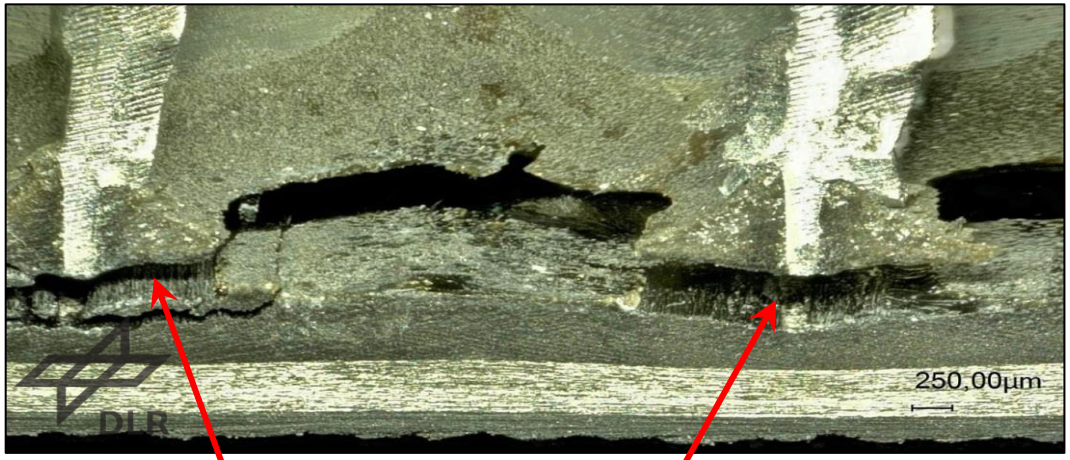
Debonding

<u>Dobonding process:</u>

- Pull out of honeycomb web
- Failure in resin fillets
- Yielding of aluminum

<u>“Smeared” determination of resistance against debonding:</u>

- Critical stress values (strength)
- Fracture mechanical characterization (resistance)



Characterization of bondline
Determination of critical stress

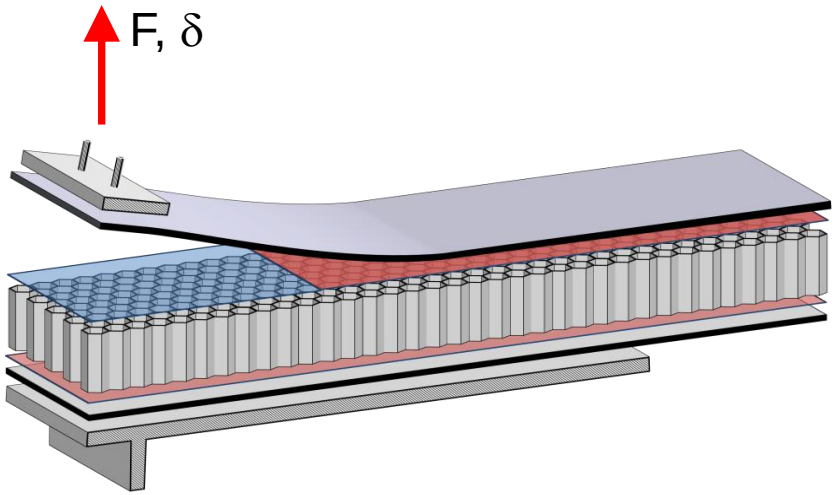
<u>Flat Wise Tension test</u>

- 50mm X 50mm specimen
- Face sheets are glued to load introducing blocks
- Adhesive must be stronger than bondline

Stress based characterization of strength R_z

Characterization of bondline

Determination of critical energy release rate

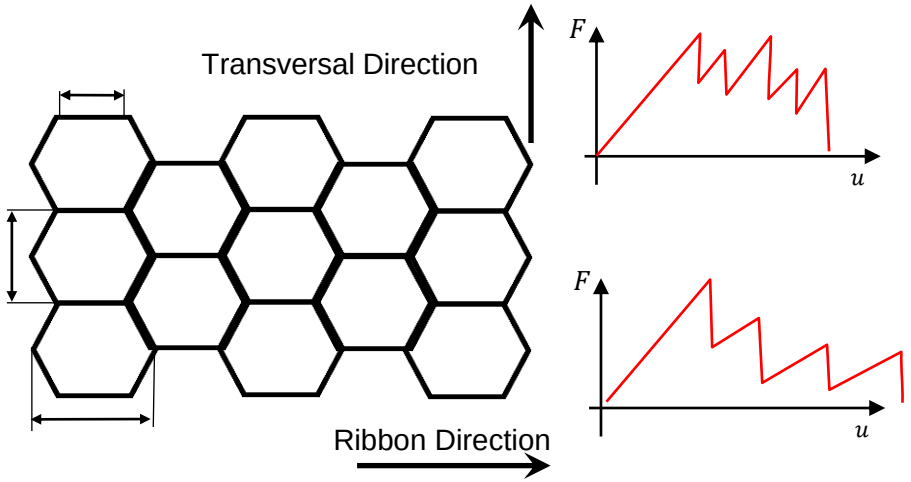


Single Cantilever Beam test

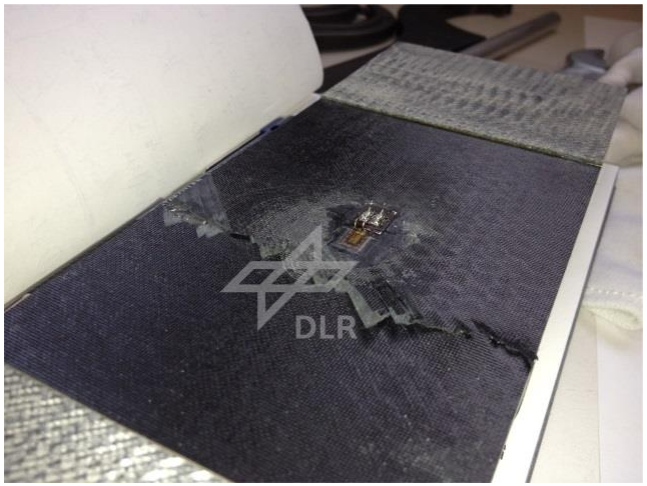
- Fracture mechanical test for peel mode I
- Derived from ASTM 5528 for monolithic composites

Challenges:

- Scientific topic (only considered for foam cores yet)
- Crack detection
- Inhomogeneous opening
- High scatter of G_{Ic} (12%)



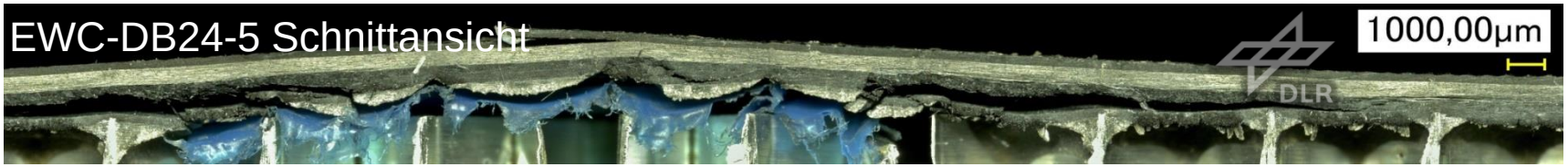
Compression Tests

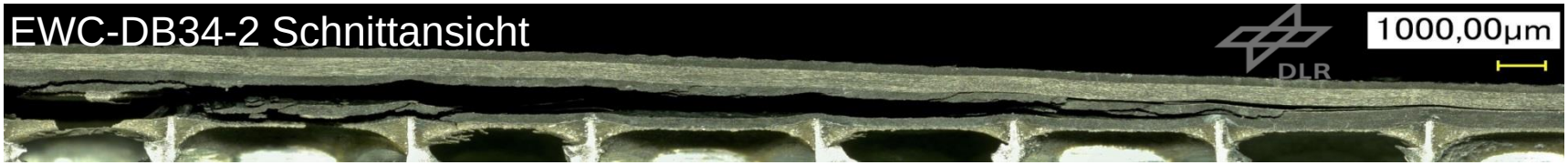


Evaluation of test setup

Occurred failure types

- Face sheet buckling
- Face sheet material failure





Valid failure type for 19 of 23 tests

DLR

Compression Tests

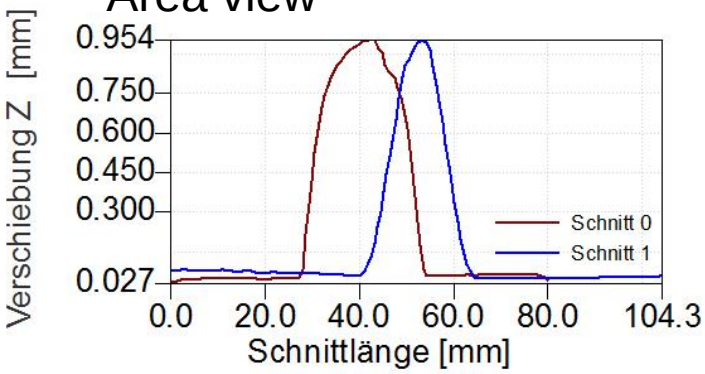
EWC results

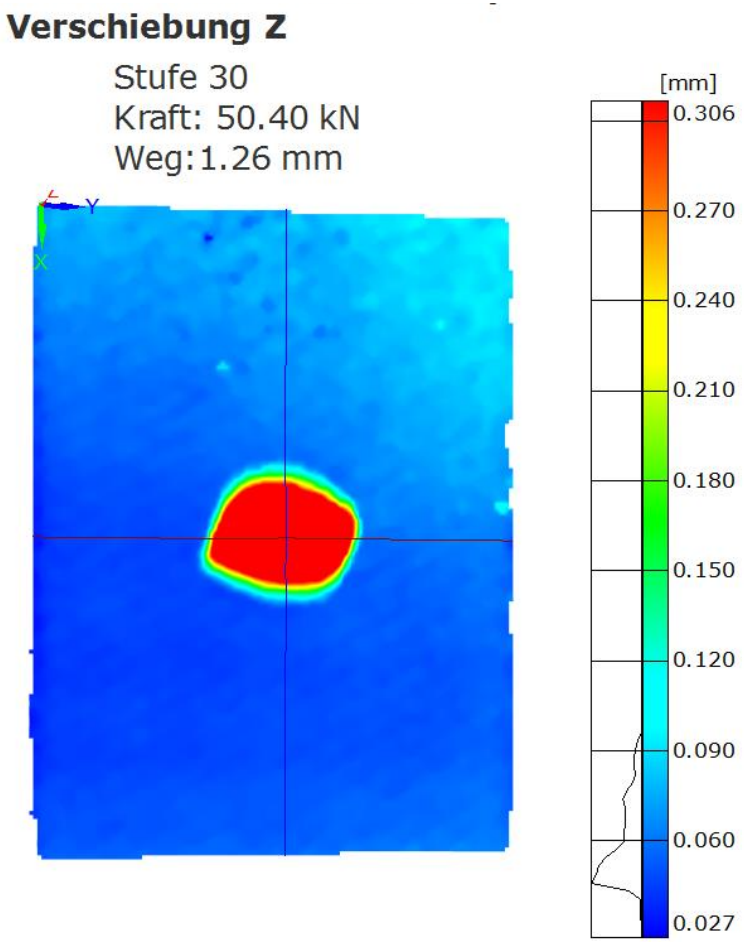
Aramis measurement –

Specimen EWC-DB24

Displacement Z

- Section view
- Area view





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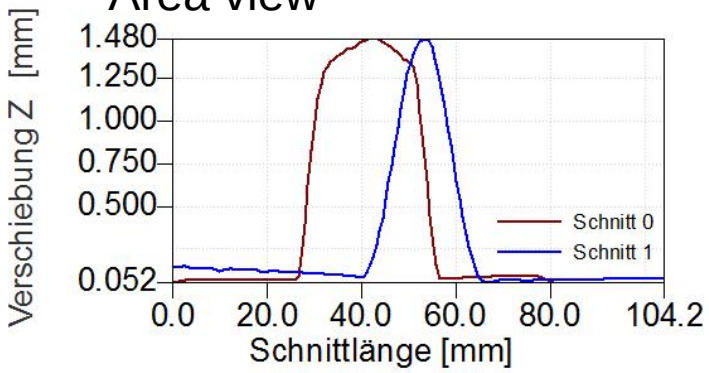

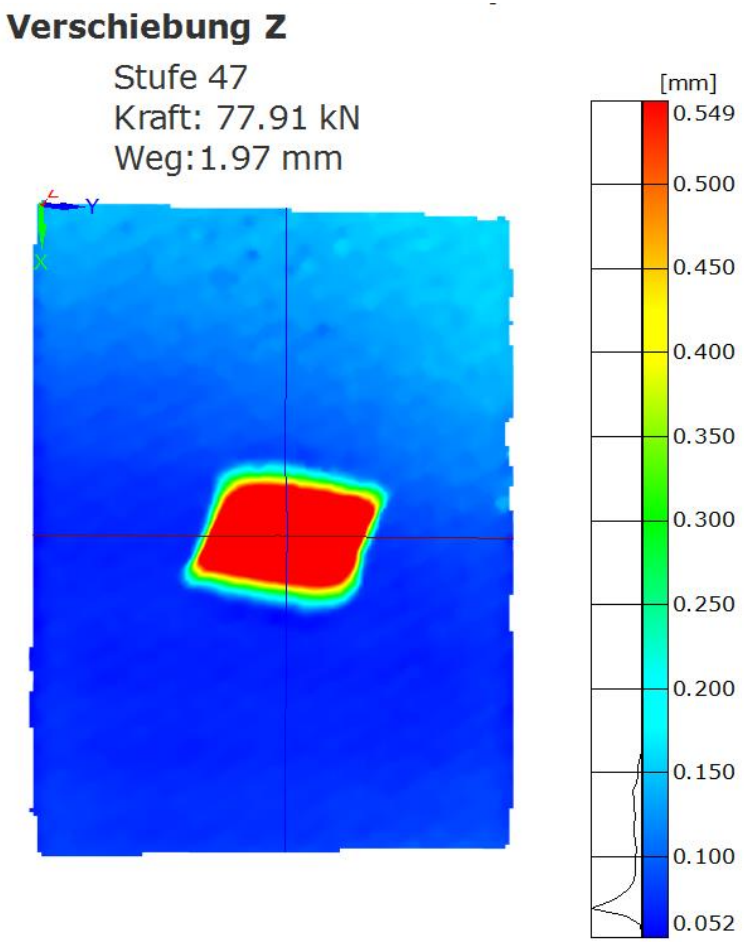

Compression Tests

EWC results

Aramis measurement –

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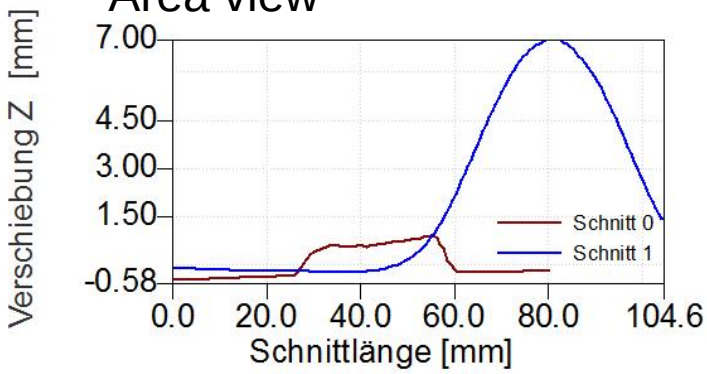

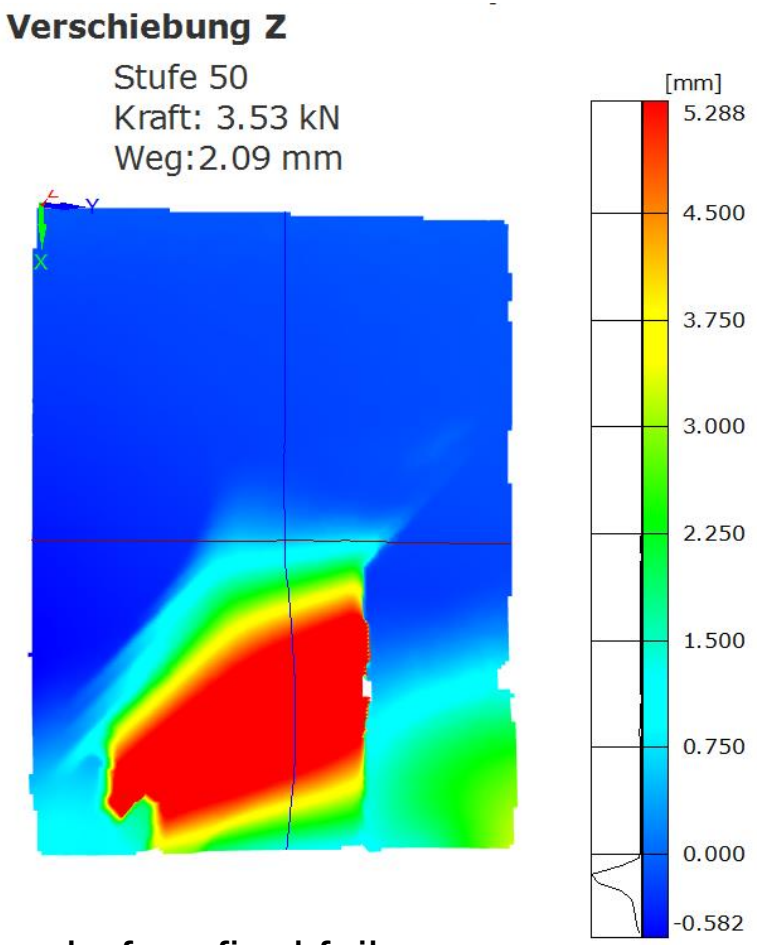

Debonding grows, especially to sides before final failure

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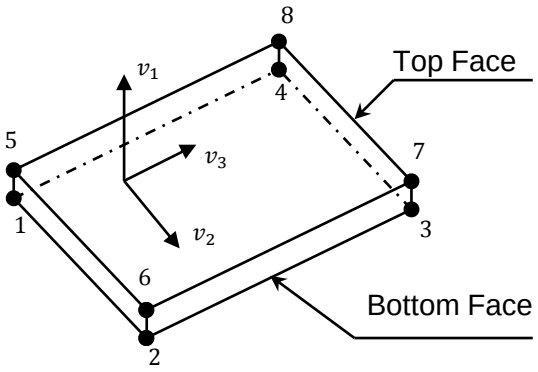
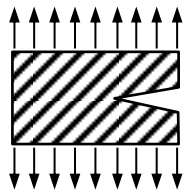
Cohesive Zone Model

Thin layer of CZE for interface

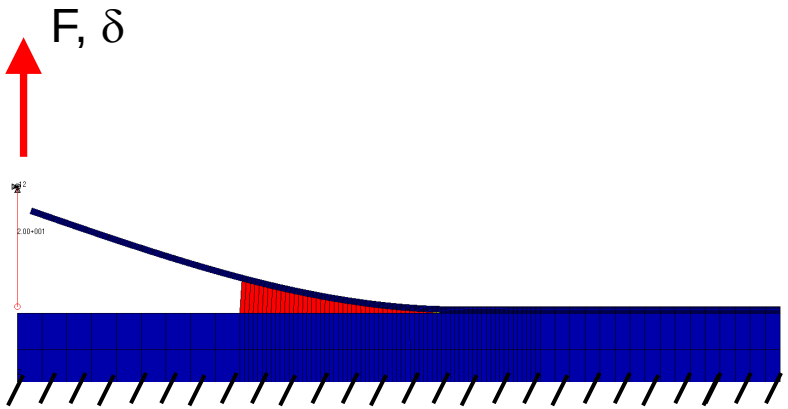
Traction separation law





Initiation and growth of cracks

SCB Model



Nonlinear implicit simulation

Marc 2013

Elements

- Linear volume elements (Hex8)
- One element per ply thickness
- 0.001 mm thick layer CZE

Materials

- 3D orthotropic material for face sheets and core
- Cohesive material with bilinear traction separation law for bondline

Load introduction with RBE2

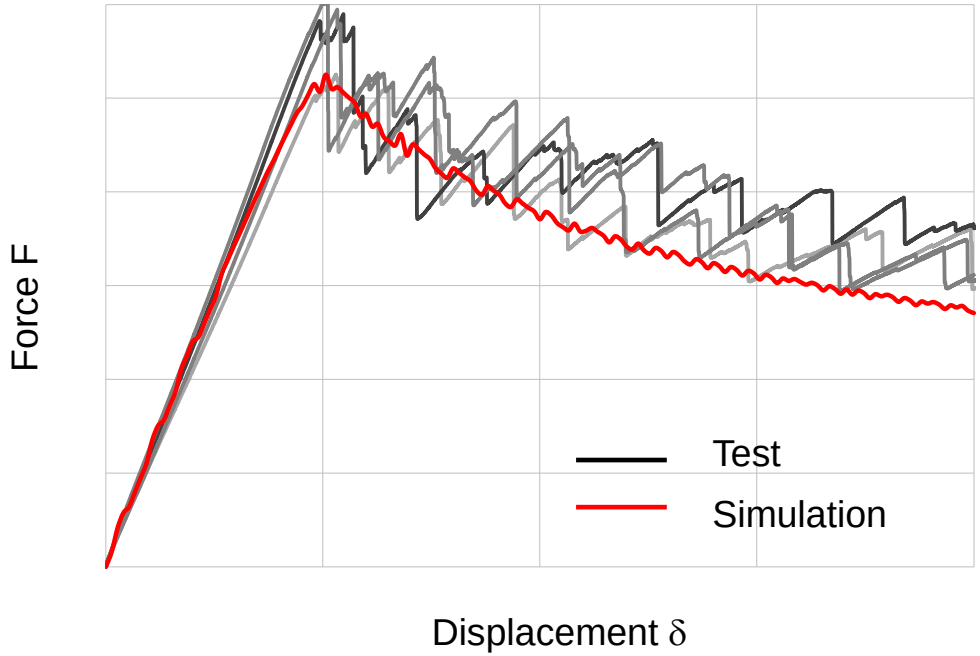
Output: Load displacement curves

Parametric Studies

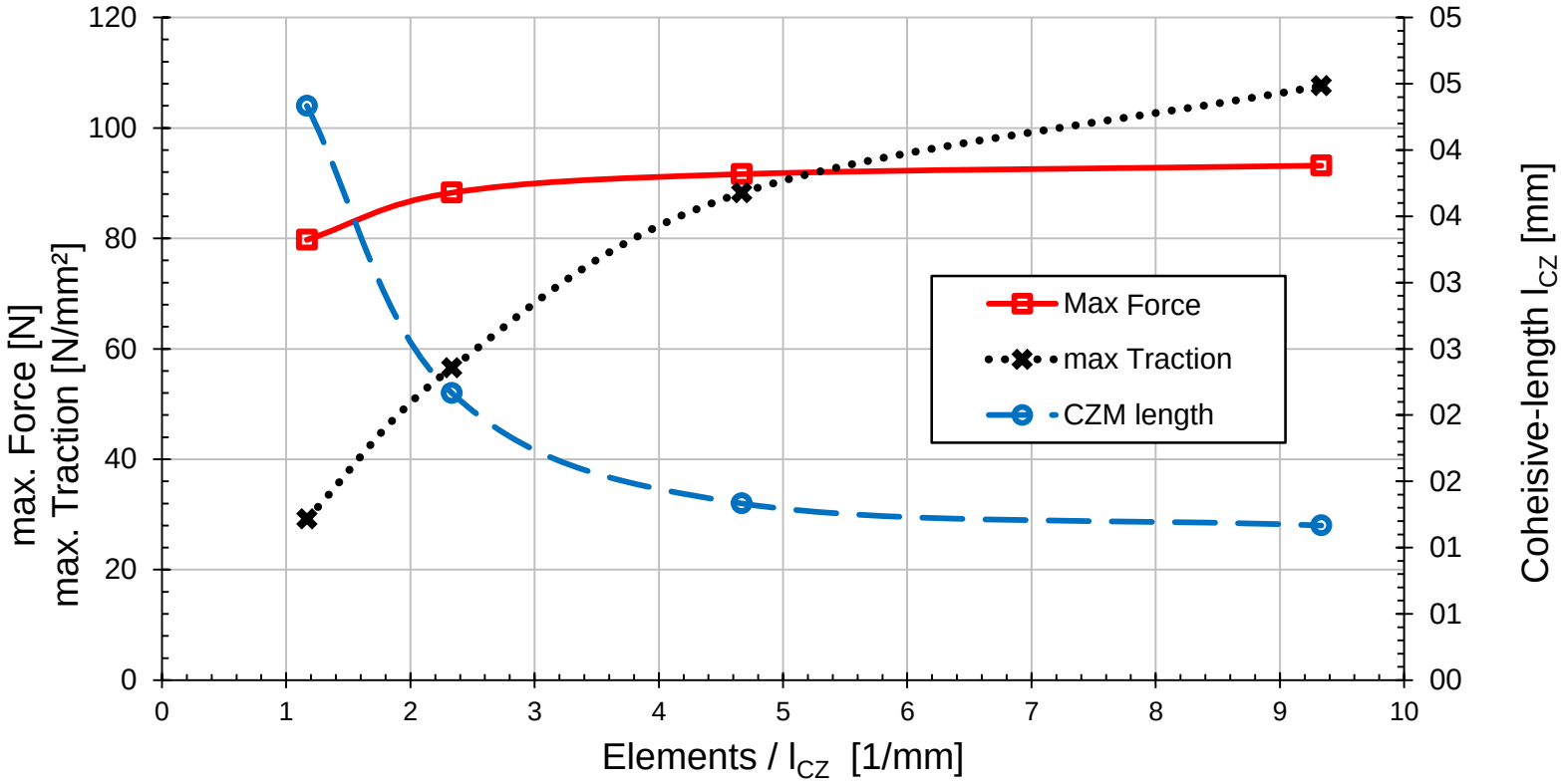
Comparison of SCB test and simulation

- Traction-Separation-Law:
  - Penalty-Stiffness
  - Critical Energy Release Rate
  - Cohesive length
  - Cohesive strength

- Numeric parameters:
  - Damping
  - No. increments



Cohesive Length

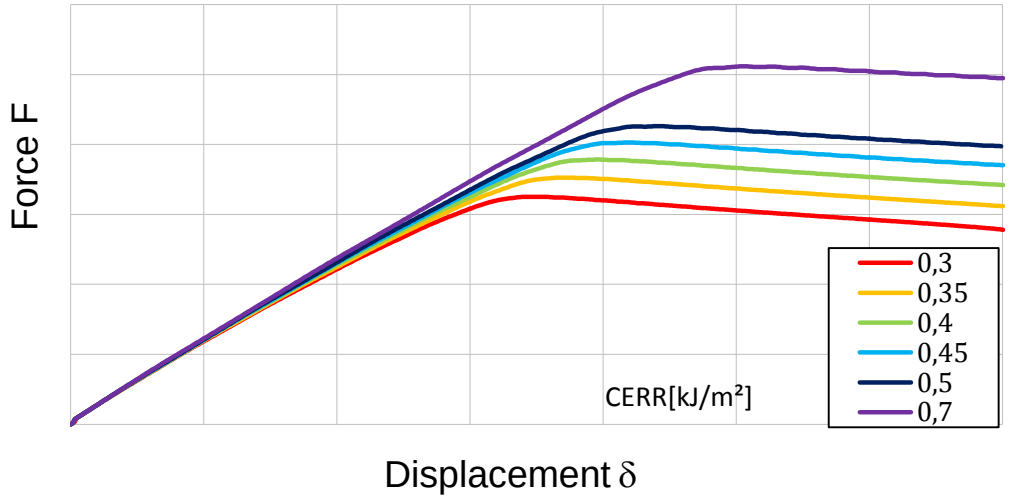


Required are 4-5 elements in cohesive zone

Cohesive Zone Parameter

Critical energy release rate (G_{Ic})

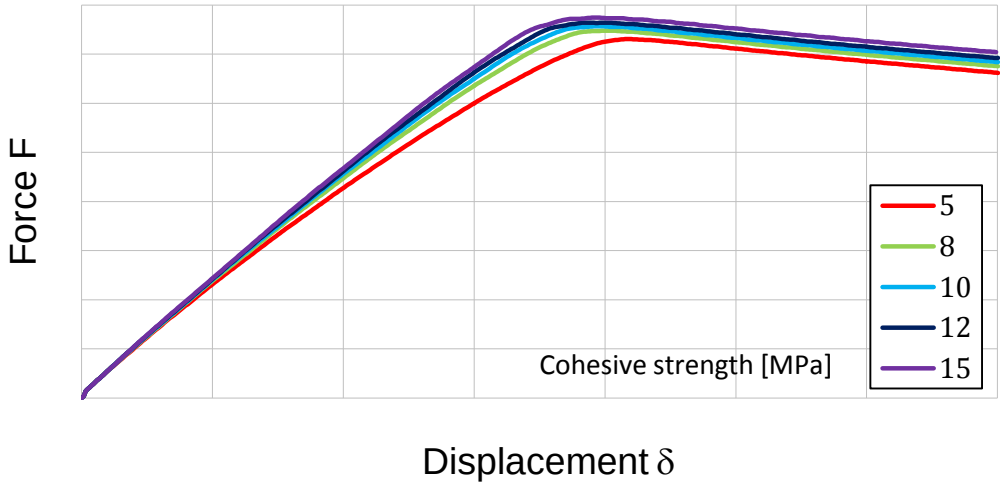
- High influence on F_{max}
- High influence on F_{NL}



Cohesive strength (τ_c)

- Low influence on F_{max}
- High influence on F_{NL}

- G_{Ic} shows large impact
- Value R_z from test lies in convergence region of τ_c

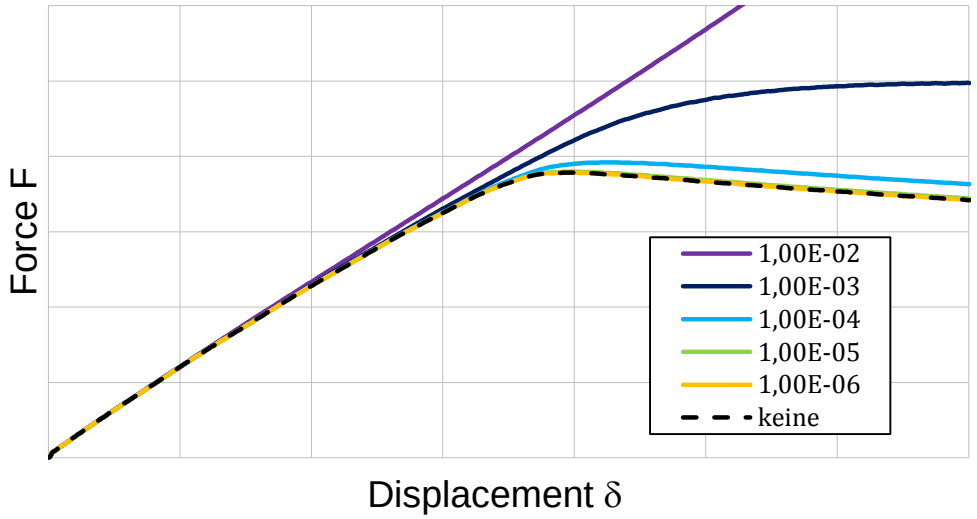


Damping

Viscous numerical damping

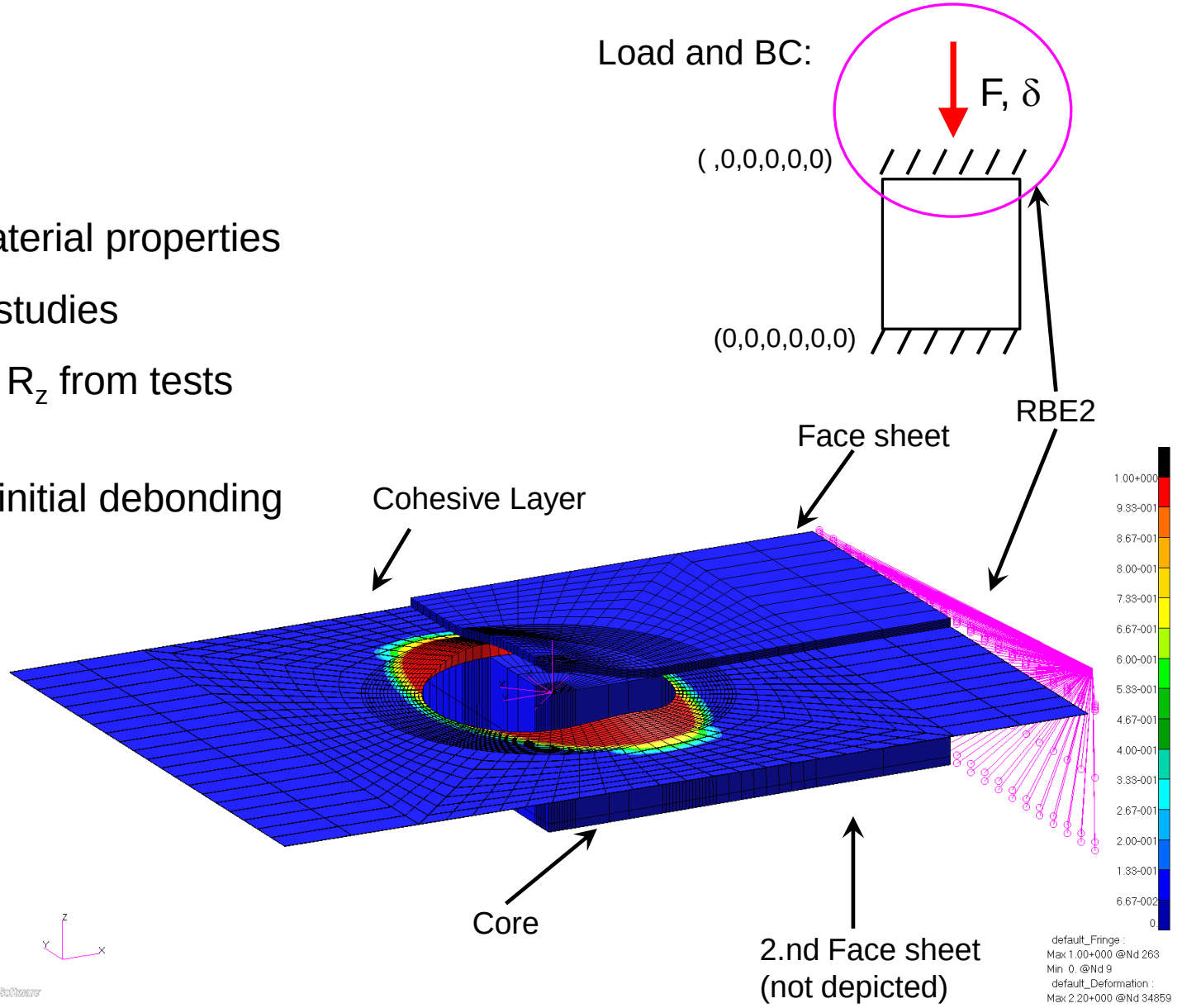
Required to achieve/increase convergence

Low impact $< 1 \cdot 10^{-5}$



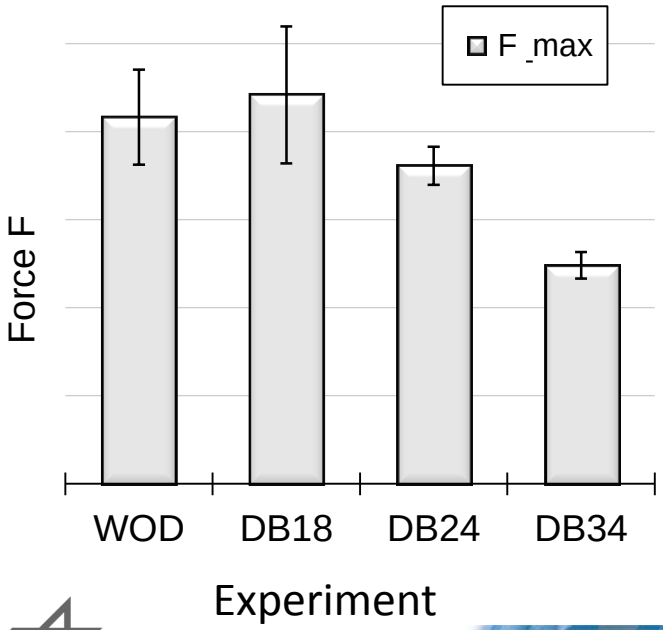
EWC Model

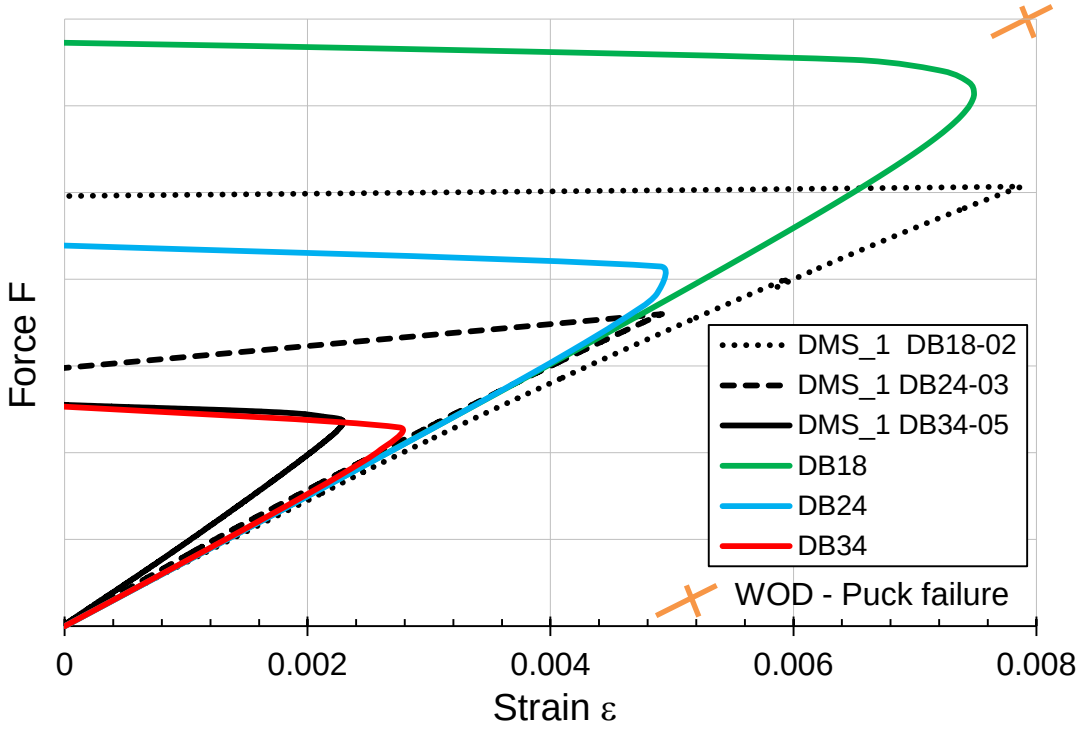
- Element and material properties
  - From SCB studies
  - G_{Ic} and $\tau_c = R_z$ from tests
- CZE left out for initial debonding
- Glued Contact
- Face sheet failure damage detected with Puck failure criterion



Results

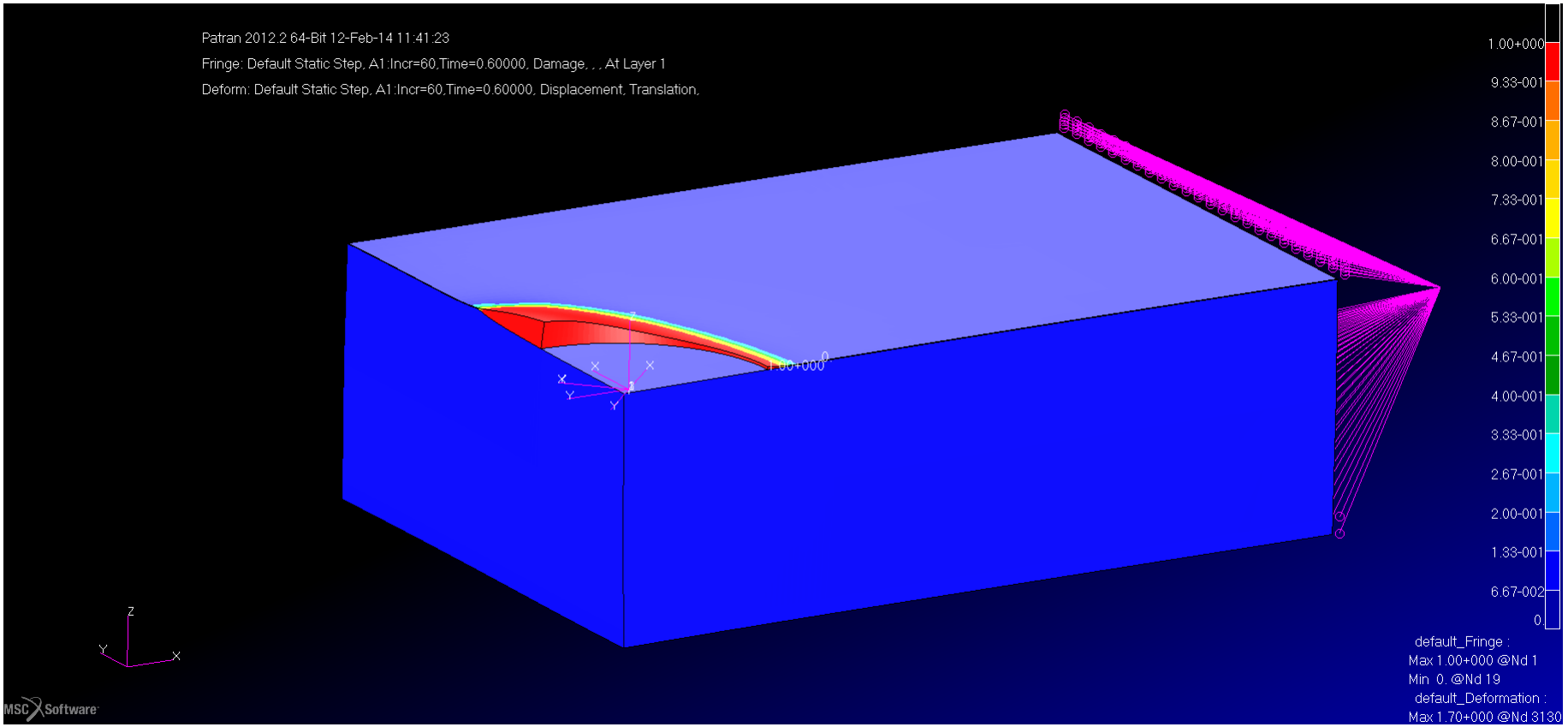
- Stiffness is well presented
- With the size of DB the deviation of F_{max} increases (smaller size=larger dev.)





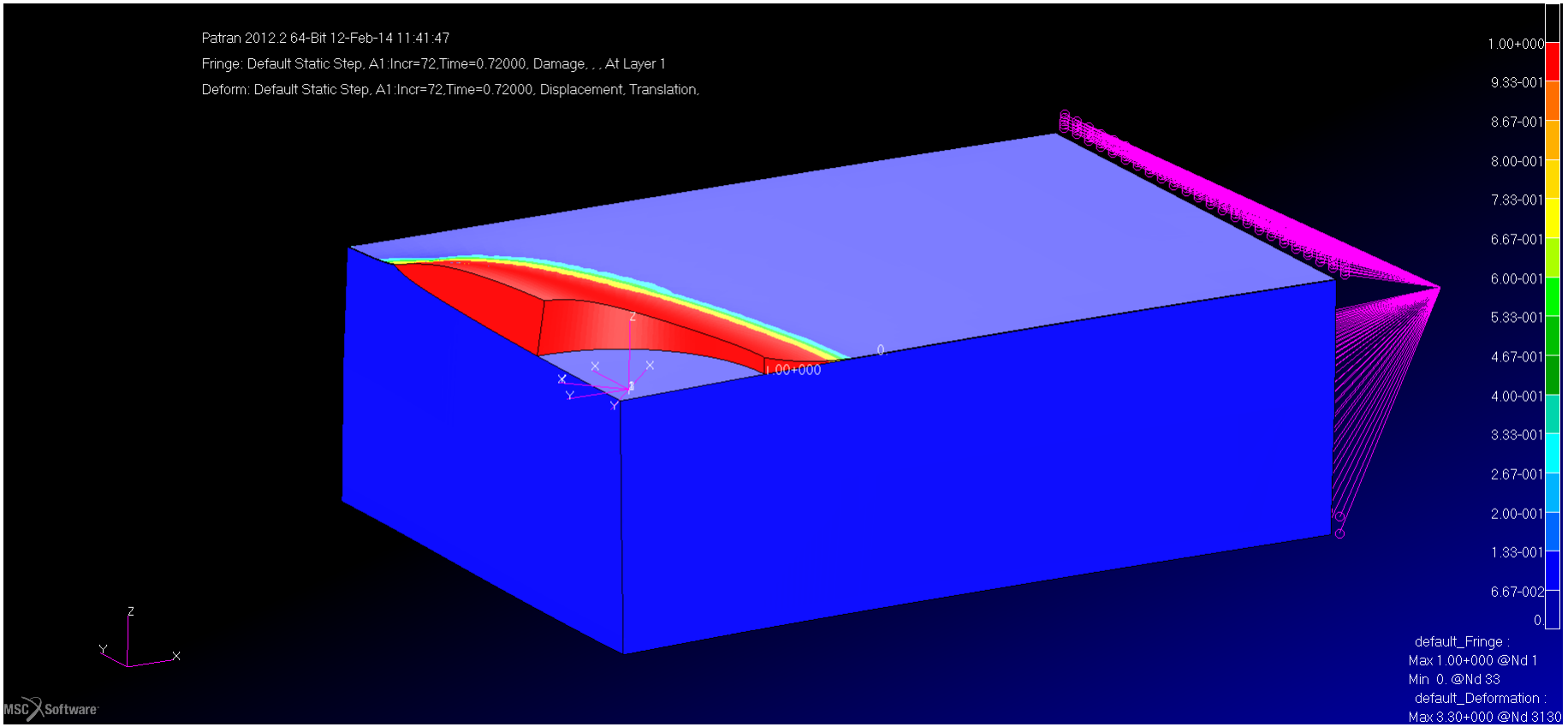
- Experiment: DB-18 shows no impact on global behavior
- Simulation: F_{max} decreases with size of DB

Results

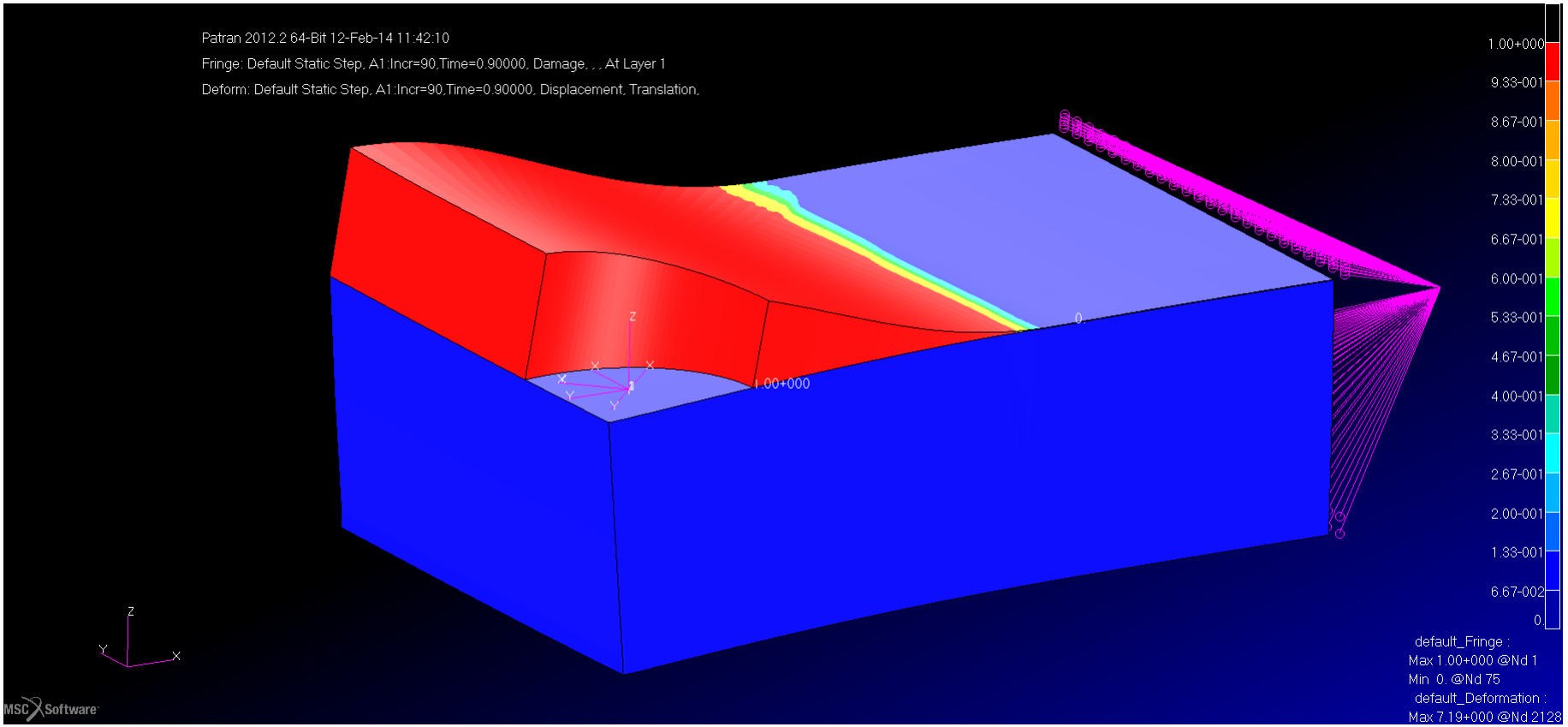


Debonding grows sideways first

Results


Patran 2012.2 64-Bit 12-Feb-14 11:41:47
Fringe: Default Static Step, A1:Incr=72,Time=0.72000, Damage, , , At Layer 1
Deform: Default Static Step, A1:Incr=72,Time=0.72000, Displacement, Translation,
1.00+000
9.33-001
8.67-001
8.00-001
7.33-001
6.67-001
6.00-001
5.33-001
4.67-001
4.00-001
3.33-001
2.67-001
2.00-001
1.33-001
6.67-002
0
default_Fringe :
Max 1.00+000 @Nd 1
Min 0. @Nd 33
default_Deformation :
Max 3.30+000 @Nd 3130
MSC Software

Results



Debonding grows sideways first

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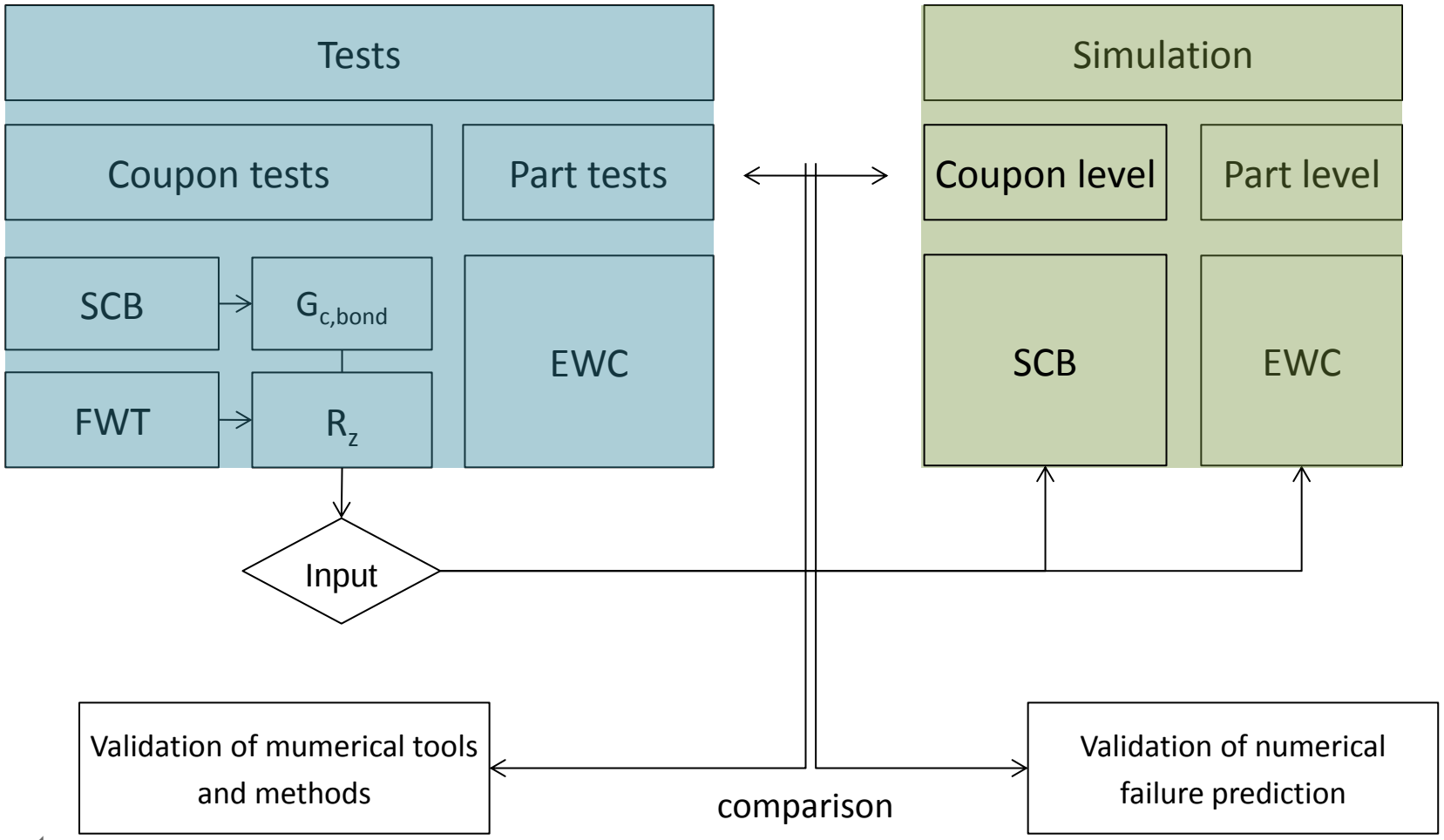
Summary


Tests
Coupon tests
Part tests
SCB
$G_{c,bond}$
FWT
R_z
EWC
Simulation
Coupon level
Part level
SCB
EWC
Input
Validation of mumerical tools and methods
comparison
Validation of numerical failure prediction

Conclusion and Outlook

Testing:

- Test series for the characterization of debonding were conducted (SCB,FWT)
  - Inhomogeneous honeycomb debonding (SCB) leads to scatter
  - Test development necessary?

- New manufacturing and test concept for EWC was developed
  Improvement to method from ASTM-C-364

Simulation

- General debonding behavior (growing sideways) can be simulated
- Simulation of larger debonding (DB-34, DB-24) agrees with test data
- Method is valid in a certain range

- Small DB-18 shows no impact in the experiment, but in the simulation
  Including of progressive damage (Softening)?

Thank you!

Enno Petersen

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